

EFFECTS OF NOISE UPON
HUMAN INFORMATION PROCESSING

by

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16. Abstract Three studies of noise effects upon human information processing are described. Whether or not effects of noise upon performance were found was seen to be dependent upon specific characteristics of noise stimulation and their interaction with task conditions. The difficulty of predicting noise effects was thus emphasized. Arousal theory was considered to have explanatory value in interpreting the findings of all three studies. Performance under noise was found to involve a psychophysiological "cost" as measured by vasoconstriction response, the degree of response "cost" being related to scores on a noise annoyance sensitivity scale, i.e., "noise sensitive" subjects showed a greater autonomic response under noise stimulation.					
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I. INTRODUCTION

Noise has long been considered an undesirable contaminant of man's environment (Committee on Environmental Quality, 1968). Extreme levels are known to be damaging to the auditory mechanism, and community noise pollution is today identified as a major source of human annoyance and as a significant societal problem (cf. Ward and Fricke, 1969). While industry commonly regards noise as an environmental stressor which degrades worker performance and productivity, it is not clear from research studies that noise typically does affect task performance adversely; indeed there is some suggestion that noise may facilitate task performance (cf. Teichner et al., 1963). Overall, however, and despite the fact that noise effects on performance have been the topic of many studies, results have been contradictory and difficult to generalize. Reviews by Broadbent (1957) and Kryter (1970) have emphasized specific problems in interpreting the results of noise research which stem from inadequacies in experimental methodology that have been a plague to this area of study.

Typically, investigations have used a variety of specific tasks which purport to measure a diversity of human (psychological) functions, e.g., perceptual, perceptual-motor, attentional, or cognitive. From more recent studies it appears that noise adversely affects performance on signal detection, choice reaction, and complex sensorimotor tasks (e.g. Broadbent, 1954; Jerison and Wing, 1957). Other tasks, yielding results in the same category, appear to demand a high level of cognitive, or attention-sharing, activity (e.g. Broadbent, 1958; Woodhead, 1964; Jerison, 1954, 1959; Dornic, 1967). Results demonstrating a facilitative effect of noise, however, are found with tasks involving either one source of input information or little cognitive activity (McBain, 1961; Kirk and Hecht, 1963; Davies and Hockey, 1966). While it is tempting to generalize that adverse effects of noise are more likely with "difficult" or "complex" tasks,

the use of such qualitative labels precludes more rigorous definition of task parameters which are likely to be sensitive to noise. In the cognitive, information processing domain, for example, the definition of complexity needs further elaboration. Results to be reported herein show noise effects to be dependent upon the level of difficulty (defined below) which varied with three different information processing tasks. The specific rationale for each of three studies is presented at the outset of each of the three major sections to follow.

The fact that under certain conditions task performance is improved under ambient noise poses difficulties for those who may wish to regard noise as a distractor (cf. Broadbent, 1957; Teichner et.al., 1963). Perhaps a more complete theoretical position comes from the idea that noise is arousing (cf. Broadbent, 1963). Evidence that noise does increase physiological arousal comes from studies showing an increase in several autonomic and cortical measures in the presence of noise (cf. Davies, 1968; Kryter, 1970; Plutchik, 1959). The relationship between arousal and performance, it has been hypothesized (Hebb, 1955), takes the form of an inverted "U", i.e., performance is poorer under conditions of underarousal or overarousal, best at some optimal level of arousal. The challenge of a task and the incentive to perform well are typically assumed to be sources of arousal. Under the above model then it is presumed that noise improves performance when task-related arousal is low, but impairs it when such arousal is already optimum-to-high. Accordingly a more demanding task is more likely to be impaired by noise. The interaction between noise (arousal) and levels of task difficulty is the subject of the first two studies reported herein. Additionally the first study reported below deals with the important question of whether performance improvement can occur during noise exposure when an individual is attending to task information.

Noise effects upon performance also appear to be a function of the temporal characteristics (patterning, continuity, or periodicity) of noise exposure; for

example, a number of studies have shown that for tasks requiring simple detection or decision responses, an unchanging noise background has no effect on task performance, while a varied noise background may improve performance (cf. Mirabella and Goldstein, 1967). On the other hand, Eschenbrenner (1971), Plutchik (1959), and Sanders (1961) have found performance on sensorimotor and other complex tasks to be differentially impaired by exposure to intermittent versus continuous noise. The third study reported herein was designed to evaluate the differential effects of noise upon cognitive task performance of periodic and aperiodic intermittent noise.

In reviewing the results of previous research on noise-performance effects, including the ambiguities which characterize many findings, it is apparent that the factor of individual differences has received little attention. The possibility that individual performance response to noise exposure could be a function of personality factors should be the topic of definitive study. Study 3 reported herein is thus also concerned with this question, and additionally explores the relationship between individual noise sensitivity and autonomic response to noise.

In toto, three studies of noise effects upon information processing task performance are described in this report. Collectively these are concerned with:

- (a) the effect of variations in the time patterning of noise exposure;
- (b) the relationship between noise-induced arousal and task difficulty (or task arousal); and
- (c) individual differences in physiological arousal response to noise.

II. STUDY 1: NOISE ONLY DURING ATTENTION TO THE TASK¹

Statement of the Problem

McGrath (1963) has summarized a theoretical position offered by Broadbent which suggests that the beneficial effect of extraneous stimulation, such as

¹Conducted by John F. O'Brien

noise, is dependent upon certain task conditions. In short, the task must be structured so that brief intervals are available when no analysis of task information is necessary. During these periods the subject performing the task can momentarily divert attention to noise stimuli. Results of studies by McBain (1961), Watkins (1964), and Davies and Hockey (1966) involving tasks which contained no such intervals, however, have demonstrated improved performance under noise. Their findings suggest that performance may be improved by noise even when the subject is attending to task information. In the present study the foregoing statement, treated as an hypothesis, was subjected to empirical test. Additionally, an attempt was made to determine how noise interacts with the cognitive demands of the task. The task required the subject to identify the number of targets (from 0 to 3) briefly presented in a visual display. Detection of each target was considered to constitute an additional cognitive demand. Thus, it was hypothesized that improvement in speed of information processing under noise would decrease as the number of correctly identified targets increased.

Method

Subjects. Eighteen male volunteer subjects were recruited from undergraduate psychology courses at the University. Each was administered, and passed in satisfactory fashion, tests for hearing loss and color blindness.

Stimulus Materials. Each of 24 signals was constructed by selecting one item from each of the three categories of stimuli that are described by Figure 1; that is, each stimulus signal contained three elements -- one from each category -- as exemplified in Figure 2. In creating the stimulus items (Figure 1) an effort was made to reduce confusion between and within categories. Thus, colors and geometric shapes were highly discriminable visually, and their names had equal ratings in the Thorndike-Lorge (1963) word list. No strong associations existed among letters (Underwood and Schulz, 1960), and none were first letters of color or shape names.

Outlines of the geometrical shapes and letters were drawn on white backgrounds with black India ink. Colors were also painted on white backgrounds in the shape shown in Figure 1. Subjects were instructed that these shapes were of no importance and were not to be confused with geometrical shapes. All stimulus signals were photographed, reproduced as 35 millimeter slides, and projected onto a 2 1/2 x 6 inch (6.35 x 15.24 cm.) screen when presented to the subject.

In terms of the subject's task the 24 stimulus signals were of four different types as defined by the appearance (or non-appearance) of "target" items. Three items (green, H, and triangle), one from each of the categories defined in Figure 1, were designated as targets for the entire study. For purposes of the task a stimulus signal could contain 0, 1, 2, or 3 targets. Each of the four types of signals was thus represented by six different slides. For purposes of description here then each of the six slides in group S3 contained all three target items, while those in groups S2, S1, and S0 contained 2, 1, and 0 targets respectively.

Individual S3 signals differed only in left to right arrangement of target items. Each target appeared twice in each position.

Construction of S2 and S1 signals was carried out in two stages. Stage I involved assignment of target items from left to right positions in the signal. For S2 signals, targets appeared in either positions 1 and 2, 2 and 3, or 1 and 3. Random assignment of targets to these positions was restricted so that (a) each target appeared four times, (b) targets appeared together no more than twice, (c) targets never appeared more than once in the same left to right order, and (d) the same two targets never appeared with the same non-target more than once. S1 signals involved presentation of targets in either positions 1, 2, or 3 as defined from left to right. Targets were randomly assigned to these positions









GEOMETRICAL SHAPES	LETTERS	COLORS
	H	
	X	
	K	
	W	

Figure 1. Stimulus items arranged by category

Figure 2. Sample stimulus signal

with the restriction that no target appeared in the same position more than once and that each target appeared twice.

Stage II first involved random assignment of stimulus categories for non-target items to the remaining positions. For S2 signals this assignment was restricted so that each stimulus category appeared twice and items from the same category appeared only once. Restrictions placed on S1 signal assignment assured that (a) each stimulus category appeared four times, (b) two categories appeared together no more than twice and (c) no categories appeared together more than once in the same left to right order. Assignment of categories to positions was followed by completely random assignment of non-target category items.

For S0 signals, stimulus categories were randomly assigned from left to right positions with the restriction that each category appear twice in each position. Non-target items for each category were then randomly assigned to category positions. Throughout the list of 24 signals each non-target item appeared four times.

S3 stimulus signals (i.e. signals containing all three target items) also served as "target availability signals". These were presented prior to the presentation of each stimulus signal. The purposes of this procedure were (a) to lower the subject's degree of cortical arousal, and (b) to ensure that he had the three targets correctly stored in active memory. Each stimulus signal was always preceded by the same target availability signal. Selection of the particular target availability signal to precede each stimulus signal was guided by a criterion which assured maximum incompatibility between the left to right order of stimulus categories in the two signals. For example, if the stimulus signal contained a color in the first position, it was preceded by a target availability signal with a color in the third position.

Noise Generation. A recording of speech played in reverse was used as irrelevant auditory stimulation (noise). According to McBain (1961), such

stimulation fulfills the requirements of variability and low intelligibility, i.e., it carries no meaning for the perceiver. The particular speech used was a recitation by a male voice of the alphabet and numerals (1-50). It was presented over a headset at an average sound pressure level of 80 dB and varied over a range of 65 dB to 94 dB.

Test Environment. Testing was conducted in an audiometric testing booth. The sound pressure level inside the booth was 22 dB. A Kodak slide projector mounted outside the booth was used to project signals through the booth observation window onto the screen. Attached to the top of the screen in the subject's field of view was a white warning light. The subject was seated at a small table facing the screen. Mounted on this table were two microphones. One fed into a voice-actuated relay and then into a small computer which measured and automatically recorded on punched paper tape the subject's response time to each stimulus signal. Response time, recorded in msec., was defined as the time interval between appearance of the stimulus signal and the beginning of the subject's verbal response. The other microphone fed into a tape recorder and enabled the experimenter to monitor subject responses and score accuracy (correct or incorrect). The same computer was used in combination with Marney Dickinson electronic timers to program the occurrence of task events and noise stimuli.

Procedure. Each trial began with presentation of a target availability signal. During this period the subject was asked to rehearse aloud the name of each target by reading the array from left to right; this was done repeatedly at his own desired rate. Rehearsal lasted 10 seconds and was terminated by illumination of the warning light. Two seconds after the warning light, the target availability signal disappeared and a stimulus signal appeared. Subjects were told to respond by saying either "0", "1", "2", or "3" depending on the number of targets appearing in the signal. A response automatically replaced

the stimulus signal with a new target availability signal and thus began a new trial. Subjects were told to respond as quickly and as accurately as possible. Hopefully, these instructions gave all subjects equal response sets for speed and accuracy. They were also told that optimum performance could best be achieved by paying attention to the left to right order of targets in the target availability signals.

Each subject received 24 practice trials followed by a two-minute rest period. During this period he sat quietly in the booth while the experimenter recycled the equipment. The rest period was followed by 48 test trials. Except for the first six practice trials when the experimenter remained in the booth to ensure that the subject performed correctly, each subject performed alone in the booth while the experimenter monitored performance from outside.

Noise, when presented, occurred simultaneously with presentation of the stimulus signal and terminated with its response. Each subject was instructed to ignore this stimulation and to perform the task as instructed.

Experimental Design. Each subject received the same random order of stimulus signals during practice trials. Randomization procedures for test trials were based on three independent variables: (1) Blocks of time, (2) Signals (S0, S1, S2, or S3), and (3) Environment (noise or quiet). There were six blocks each containing eight trials. Within each block two different members from each stimulus signal group were presented (one in quiet and the other with noise). Thus, ignoring individual stimulus signals and considering only stimulus signal groups, each block contained eight treatment conditions. The first randomization procedure, carried out separately for each subject, produced a completely random order of these treatments for each block. The second

procedure was then conducted separately for each of these treatments and involved assignment of the six individual members from each stimulus signal group. This was accomplished by use of a six-element, balanced Latin square, which assured that individual stimulus signals were balanced with respect to blocks for each treatment condition.

Results

Three sets of data were available for analysis: (a) response times for 804 correct responses (response times for 10 correct responses were missing as a result of mechanical failures), (b) response times for 50 incorrect responses, and (c) total number of correct and incorrect responses. The first two sets of data were subjected to a least squares analysis of variance for unbalanced designs and the third to a chi-square test of independence.

In the case of the data for correct responses, as may be seen in Table I, statistically significant main effects were found for Subjects, Environment (Noise), Signals, and Blocks; however, none of the interactions was significant.

TABLE I. ANALYSIS OF VARIANCE OF RESPONSE TIME (ERRORS EXCLUDED)

Source	df	MS	F
Subjects	17	1,391,301.62	34.81***
Environment (Noise)	1	218,380.93	5.46*
Signals	3	516,858.72	12.93**
Blocks	5	285,408.04	7.14**
Env. x Signals	3	22,545.08	0.56
Env. x Blocks	5	50,672.37	1.27
Signals x Blocks	15	30,590.37	.77
Env. x Signals x Blocks	15	16,027.25	.40
Error	740	39,969.02	
Total	804		

* $p < .02$

** $p < .01$

*** $p < .001$

Mean response time recorded while subjects were exposed to noise (968 msec.) was faster than mean response time recorded under quiet conditions (1001 msec.). Marginal means for the six blocks were respectively 1059, 1007, 991, 953, 949, and 949. An improvement in mean response time of approximately 100 msec. occurred over the first four blocks; however, times for the last three blocks were fairly stable.

Mean response times for S0, S1, S2, and S3 stimulus signals were respectively 989, 1013, 1030, and 910 msec.; these were compared using Duncan's New Multiple Range Test. All three comparisons involving S3 stimulus signals were statistically significant ($p < .05$), the S3 stimulus signals being processed in less time than any other signal. A statistically significant ($p < .05$) difference was also found between the means for S0 and S2 stimulus signals.

The second analysis concerned the 50 response times for incorrect responses. As may be seen in Table II, the only statistically significant source of variation among incorrect response times was Subjects. None of the experimental conditions had an effect on these response times. The response time for one incorrect response was inaccurately recorded and thus excluded, reducing the sample size to 49.

TABLE II. ANALYSIS OF VARIANCE OF RESPONSE TIME (INCORRECT RESPONSES)

Source	df	MS	F
Subjects	17	85,980.27	2.41*
Environment (Noise)	1	43,246.91	1.21
Signals	3	17,169.68	.48
Blocks	5	45,827.28	1.28
Environment x Signals	3	31,306.60	.87
Error	19	35,626.96	
Total	48		

* $p < .05$

The third analysis was undertaken to determine whether the 50 incorrect responses were equally distributed among (a) the two environmental conditions, (b) the four stimulus signal groups (S0, S1, S2, S3), and (c) the eight environment x stimulus signal conditions. Three chi-square tests of independence were performed, and these indicated that the occurrence of errors was independent of environment ($\chi^2=.042$; 1 df; $p > .05$) and environment x stimulus signal classification ($\chi^2=2.88$; 7 df; $p > .05$), but dependent on stimulus groups ($\chi^2=25.70$; 3 df; $p < .05$). Most of the errors occurred when subjects were responding to either S1 or S2 stimulus signals as revealed in Table III.

TABLE III. TOTAL NUMBER OF CORRECT AND INCORRECT RESPONSES FOR EACH STIMULUS SIGNAL GROUP

	Stimulus Signal			
	S0	S1	S2	S3
Correct	210	199	187	208
Incorrect	3	14	26	7

One final analysis was undertaken to determine if mean response time for incorrect responses was different from that for correct responses. These data were also analyzed using a least squares analysis of variance (Table IV) for unbalanced designs which produced a sum of squares for the correct-incorrect comparison adjusted for the effects of subjects, signals, environment, and blocks. The analysis shows that mean response time for incorrect responses (958 msec.) was significantly faster than for correct responses (984 msec.).

TABLE IV. ANALYSIS OF VARIANCE FOR THE EFFECT OF CORRECT-INCORRECT RESPONSES ON RESPONSE TIME

Source	df	MS	F
Subjects	17	1,432,754.10	36.378
Environment (Noise)	1	133,752.89	3.79
Signals	3	501,491.89	12.73
Blocks	5	287,097.38	7.29
Correct-Incorrect	1	152,635.95	3.87*
Error	836	39,395.11	
Total	863		

*p < .05

Discussion²

The hypothesis that signals presented with noise would require less time for correct processing than signals presented in quiet was supported by the results. Both the noise and task conditions used in this study would favor an arousal theory explanation of this finding. While one could argue that both the presentation of the warning light and the subsequent demands placed on the subject in terms of responding to task signals were stimulating, it was assumed that other aspects of the task lowered cortical arousal. During the interval preceding each stimulus signal, the subject was asked to repeatedly rehearse the names of the three targets present on the screen. Each subject was engaged in this highly repetitive rehearsal for 70 percent of the experimental session. Also he received little auditory input as a result of confinement in the audiometric testing booth. Thus, it seems plausible to assume that subjects experienced a considerable reduction in variability of stimulation which arousal theorists agree is necessary for optimum arousal of the cortex. According to arousal theory, presentation of an additional, arousing stimulation (under such conditions) should improve performance.

²Theoretical implications of the results for a model of human information processing are discussed at greater length in O'Brien, 1972.

The noise used in the present study could be considered additional, arousing stimulation for two reasons. It was both variable and intense. The results of both the McBain (1961) and the Kirk and Hecht (1963) studies indicate that variability of noise is important. In the McBain study noise was a recording of speech played in reverse and involved changes in both frequency and intensity. Noise used in the present study was also speech played in reverse, and it involved as many as five intensity changes per second. The average change was approximately 10 dB. Also, since noise did not occur on all trials, its presentation represented a sudden change from almost complete quiet to auditory stimulation. Similarly, Watkins (1964) has found that a mode of presentation similar to the one used in this study was more beneficial to performance than continuous noise. Both physiological data (Helper, 1957; Blum et al., 1967) and performance data suggest that intense noise is arousing. The average intensity of the noise used in the present study was 80 dB with peaks as high as 94 dB. Thus, it seems reasonable to attribute the facilitation produced by noise in the present study to increased arousal.

According to Broadbent, arousal can be augmented only when a subject's neural filter selects noise stimuli, and, at such times, response to task information is not possible. Conversely, he seems to suggest that during periods when the subject is processing task information, noise is completely filtered and has no effect on behavior. Results of the present study challenge both of these assumptions. Noise was presented only during periods when the subject was required to process and respond to stimulus signals, and, as the results indicate, the beneficial effect of noise occurred during these periods. Thus, this finding suggests that noise is not completely rejected by man's nervous system when he is processing task signals.

In terms of Broadbent's model, two possibilities deserve mention. First, noise and task information (stimulus signals) could have been selected concomitantly by subject's neural filter and both dealt with as a cue. However, this seems unlikely since Broadbent's assumption that irrelevant inputs are filtered is supported by research in other areas. For example, Norman (1968) reviewed several studies showing that when subjects are stimulated at each ear with a different message, they have no problem accepting one message and rejecting the other. Since noise in the present study was irrelevant to performance of the task and contained little or no information, it seems plausible to assume that it was rejected as a cue. As a second alternative, noise could have been routed through the arousal system and filtered before reaching the cortex as a cue. While this explanation disagrees with Broadbent's notion that noise must be selected by the filter as a prerequisite to increasing arousal, it seems more plausible in view of existing data.

It was also hypothesized that processing a difficult signal would arouse a subject more than processing a less difficult signal. Thus, it was predicted that an increase in arousal would have a greater effect for the easiest signals. Results did not support this hypothesis. Further, mean response times for the stimulus signal groups did not vary as a function of the auditory environment. Perhaps an increase in arousal produced by signal difficulty, if it occurred, was insignificant in comparison to that produced by noise.

The task used in this study was somewhat unique. Results obtained with other tasks suggest that the effect of noise is to aid the subject in focusing attention on the task at hand. In the present study, the task was designed so that the subject would have no problem determining when stimulus signals were to appear. Each stimulus signal was preceded by a warning light and immediately prior to its appearance, the target availability signal disappeared and the screen became dark.

Thus, it would seem that his attention should have been adequately focused. Furthermore, the noise did not occur until he was processing the stimulus signal; hence, it would seem that the facilitative effect of noise was not at the level of attentional processes but at a more central level.

Whether one favors an arousal model or not, the findings of this study strongly suggest that: (a) noise improves man's ability to respond rapidly to visual information; (b) in contrast to Broadbent's position, this improvement may occur while man is processing and responding to task information.

III. STUDY 2: NOISE AND TASK DIFFICULTY³

Statement of the Problem

When a worker is already thought to be performing at his capacity, it is argued that additional task demands must lead to some compromise in efficiency, e.g., failure to respond, errors. Increasing both noise level and task load along some quantifiable dimension (e.g., task speed) should raise an individual's level of arousal by increasing the overall level of stimulation. Under conditions of overarousal, performance decrement is to be expected.

Industrial workers are often required to perform at serial repetitive, machine-paced tasks, quite often at very fast speeds, not uncommonly in loud ambient noise conditions. Frequently, noise exposures are aperiodic. This form of noise, unpredictable in time, appears to have a more adverse effect upon the performance of demanding tasks than either continuous or periodically intermittent noise (cf. Eschenbrenner, 1971). Thus the interaction effects of work pace and aperiodic noise are of both practical, as well as theoretical interest.

³Conducted by H. Harvey Cohen

Increasing the speed at which task relevant signals are presented results in a reduction of the time available for decision-making. Therefore, if one is to respond to a signal, he must do so more quickly, thus increasing the likelihood of decision errors. If the signal rate is very fast, i.e., if it exceeds the individual's channel capacity, a number of signals may be missed altogether, since the individual cannot respond quickly enough to the signals, thus resulting in another kind of error, i.e., omissions. In order to cope with the speed stress imposed by an increasingly fast signal rate, an individual may adopt either of two possible response strategies: (1) he may keep up with the fast work pace and consequently commit more decision errors, or (2) he may filter out more task relevant stimuli, i.e., omit more signals, as his limited capacity decision mechanisms fail to cope with the increasing queue of serially-presented, discrete signals. A fast-paced task should demand more of an individual's limited information handling capacity than a slow-paced task and should, therefore, be more prone to the adverse effects of noise stress. According to arousal theory, under both noise and speed stress conditions, the individual should exhibit a breakdown in efficient performance, thus increasing error production, as his limits of efficient performance are exceeded.

In the work to be reported, the following hypotheses were tested: (1) noise would adversely affect performance on a paced, serial repetitive task; (2) the faster the work pace, the poorer would be performance; and (3) noise would more adversely affect performance at fast work paces than at slower work paces.

Method

Subjects. Six male subjects were recruited from the undergraduate student population at the University. Their ages ranged from 21 to 26 years with a median of 23 years. Each subject was individually screened for normal hearing before

participating in the study. "Normal" hearing was operationally defined as a detectability threshold of no greater than 35 dB at any test frequency. As determined by standard audiometric methods, all subjects had normal hearing within the frequency range of 250 to 8000 Hz.

Task Apparatus. Adapted from a discrimination reaction time apparatus used by Chambers (1963), the four-choice serial task to be described involved a single intervening decoding operation between stimulus presentation and subject response. The additional decoding, plus a less compatible arrangement of stimulus lights and response buttons as shown in a sketch of the apparatus (Figure 3), should increase the cognitive requirements imposed upon the subjects (in contrast to a simple four-choice task); this theoretically at least should enhance the sensitivity of the task to environmental stress in general, and to noise in particular.

The task operates as follows: one of the four stimulus lights is randomly illuminated signaling the operator to respond as accurately as possible with one of the four response buttons according to the displayed code (see Figure 3). The top-to-bottom position of the illuminated light directs the subject to a left-to-right position in the code. That digit, contained in the designated position, in turn indicates which button from left to right is the appropriate response. If, for example, the light in position three is illuminated, the subject should, according to the sample code (4213), press response button one (left to right) in order to score a correct response. Pressing any other button is recorded as an error. If the first light goes on, the subject should press response button four, and so on. After each trial another light and code automatically appears according to two separate random programs, one for the lights and one for the codes.

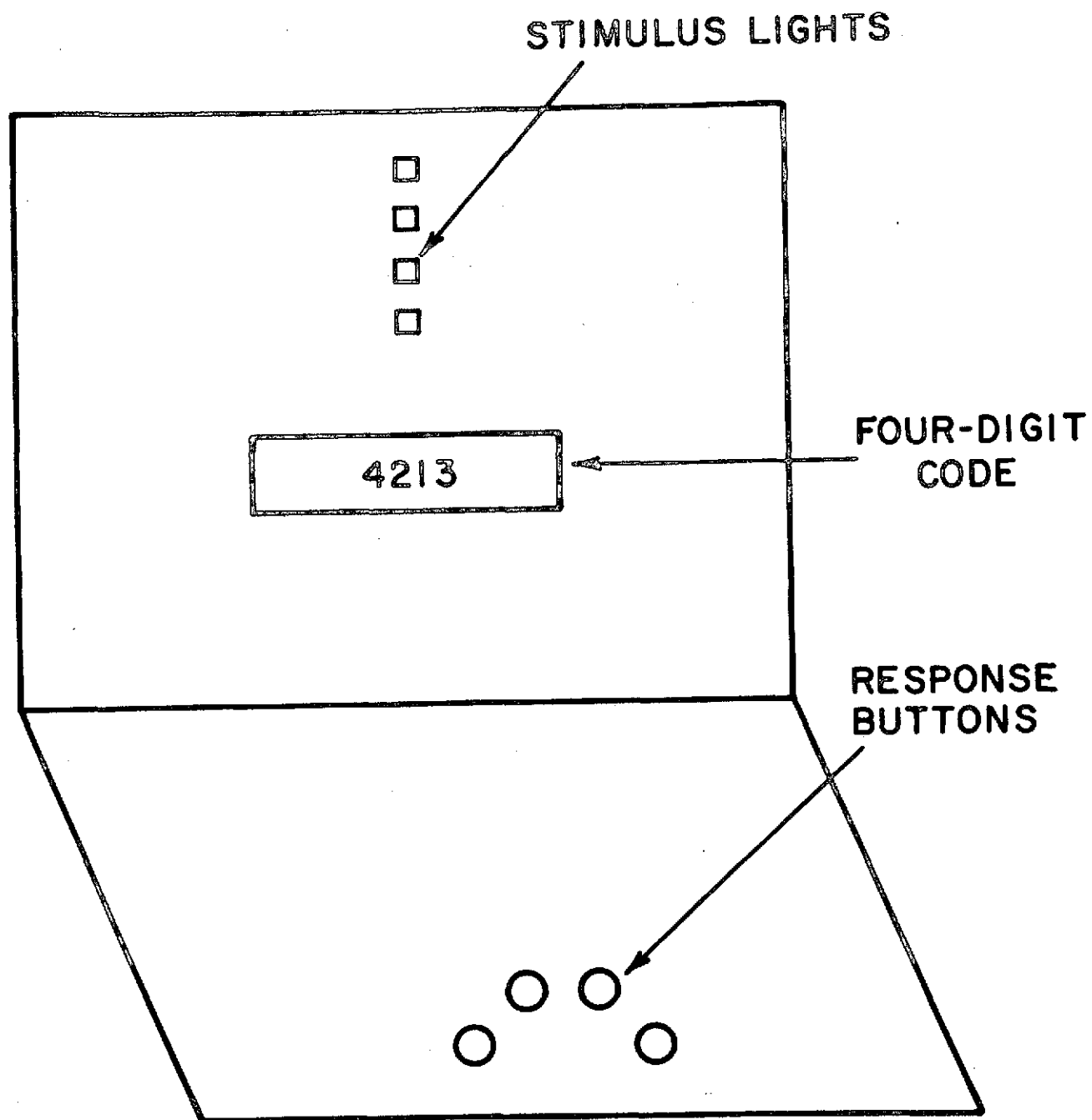


Figure 3. Four-choice serial task

The four-digit code was presented on a rear-projection type display. Random order of presentation of 12 codes was used: 2143, 2314, 2341, 2413, 3142, 3241, 3412, 3421, 4123, 4132, 4312, 4321. The four response buttons were microswitch-operated. Task programming and logic circuitry are described in detail elsewhere (Cohen, 1972). For this research the task display panel was located in a double-walled acoustical chamber.

Random programs for both the lights and the codes were frequently changed. Separate counters recorded (1) total trials presented, (2) total responses, and (3) total correct responses. Subtracting (3) total correct responses from (2) total responses yields total incorrect responses (decision errors). Subtracting (2) total responses from (1) total trials presented yields a second type of error score, total omissions.

Noise Generation. The noise stimulus consisted of rapid intermittent pulses of broadband noise produced by a Bruel and Kjaer random noise generator, type 1402. The intermittent noise was presented aperiodically, such that noise durations were constant, but internoise intervals varied randomly about a mean value within a specified range. Both noise durations and internoise intervals were automatically generated by Massey Dickinson timing and programming equipment. This circuitry (Cohen, 1972) produced 10 randomly-selected internoise intervals ranging from .150 sec to 1.50 sec in 10 equal .150 sec steps. The mean internoise interval was, therefore, .825 sec; noise duration was held constant at 1.00 sec.

Subjectively, the rapidly intermittent, aperiodic noise was quite like that produced by a wide variety of office and computing equipment, e.g., typewriters, calculators, keypunches, teletypes, printers, etc., i.e., rapid, intermittent pulses of constant duration, broadband noise separated by rapid, variable internoise intervals. Such noise is frequently encountered in industrial operations as well, e.g., many automated or semiautomated assembly processes (Fornwalt, 1965).

Noise level at the earphones (Telex Model 1200-42) was measured to be 100 dB(A). A plot of the measured octave band frequency spectrum appears in Cohen, 1972.

Experimental Design. Two independent variables, task speed and noise level, were experimentally manipulated. A third independent variable, time at work within sessions, was also evaluated. Three levels of task speed or work pace, qualitatively referred to as slow, medium, and fast, were presented. In the slow work pace (task speed) conditions stimuli were serially presented for 2.0 sec duration, i.e., a subject had 2.0 sec in which to make a response. In the medium work pace conditions stimuli were presented for 1.5 sec, and in the fast work pace conditions a subject had only 1.2 sec in which to respond. Thus, 30, 40, and 50 signals/min were presented in the slow, medium and fast work pace conditions respectively.

Two levels of the second independent variable, noise intensity, were also presented for each of the three levels of task speed. The "quiet" conditions were operationally defined as 50 dB(A) of aperiodic noise while 100 dB(A) of aperiodic noise defined the "noise" conditions.

Data on the third independent variable, time at work within one-hour sessions, was sampled regularly at five-minute intervals. For analysis, however, it was decided to aggregate the time-sampled data into four 15-minute time blocks.

A repeated measurements model was employed with each subject receiving all experimental treatments, thus serving as his own control. Each subject, therefore, received a total of six experimental treatments--three levels of task speed for each of two noise environments. The order of the six experimental treatments was independently randomized for each subject, such that each subject received a different random order of experimental treatments. Random orders were selected

so that experimental treatments always occurred on different days for all subjects. Therefore, any possible effects of having one treatment following another, or of learning effects confounding treatment order, were effectively counterbalanced.

Each of the six treatment conditions was presented to subjects on six different days, i.e., one day per experimental treatment. Subjects performed the task continuously for one hour under each treatment condition. Therefore, each treatment constituted a separate one-hour session. Each subject participated in a total of seven one-hour sessions on seven consecutive weekdays.

Procedure. In the first one-hour session each subject was trained on the task at the fast speed (50 signals/min) and in quiet (50 dB(A)). Pilot work established that performance stabilizes at all three task speeds in less than one hour of practice. The fast task speed was selected for training, since the fastest speed was naturally the most difficult. Each hour training session was divided into 12 five-minute work periods, separated by brief rest periods, during which the experimenter gave each subject summary feedback and suggestions for improving his performance.

Before training began, task instructions were read and audiometric tests for normal hearing were taken. At the start of the second session on day 2 additional instructions were read explaining the procedures to be followed for the succeeding six experimental sessions. In addition, subjects were instructed to take comfortable sitting positions and were encouraged to frequently change their hand, arm, and sitting postures in order to minimize discomfort during the one-hour work sessions. Before the start of each daily session, audiometric checks against possible temporary threshold shift and 48 warmup task trials were administered.

All subjects were paid an hourly rate of \$3, or a total of \$21 per subject for the seven work sessions. In addition, a \$10 bonus was offered to the person having the best overall performance scores at the end of the study as an additional incentive for maintaining a high level of performance throughout the study.

In addition to the experimental controls already discussed, several variables which have been shown to affect task performance specifically were also controlled. Temperature within the environmental chamber was held at a comfortable 70° F. Illumination was artificial, indirect in order to prevent glare, and was unvarying for each subject. All tests were run between the hours of 9:00 A.M. and 5:00 P.M., each subject working the same hour on each of his seven test days.

As previously discussed, the task was paced, such that the operator had to make a response, either correct or incorrect, in the allotted time, or an omission was recorded. In order that all subjects should adopt a common response strategy, subjects were instructed to try to respond to each event. This had the effect of minimizing omissions.

Results

Since task speed was varied as an independent variable, a different total number of events was presented in one-hour sessions for each of the three task speeds. Thus, the slow task speed (30 signals/min) presented a total of 1800 signals during one-hour sessions while the medium (40 signals/min) and fast (50 signals/min) task speeds presented 2400 and 3000 total signals respectively during one-hour sessions. In order, therefore, to compare performance among the three different task speeds, all measures were first converted to percentage scores.

Mean performance scores attained during training revealed that performance did, in fact, stabilize in less than one hour of practice, thus confirming the

pilot data. Additional discussion of the pilot testing and training data, and of the statistical analysis approach used herein, appears in Cohen, 1972. Prior to the principal analysis of variance, to be discussed next, an arcsin transformation of the percentage score data was performed.

Results of the analysis of correct response data (Table V) revealed a highly significant noise condition main effect, work pace main effect, and noise condition x work pace interaction ($p < .001$). Figures 4 and 5 illustrate the noise condition and work pace main effects respectively. Figure 6 demonstrates the noise condition x work pace interaction effects. Also significant ($p < .025$)

TABLE V. ANALYSIS OF VARIANCE (CORRECT RESPONSES)

Source of Variance	df	MS	F
Noise condition (N)	1	3.98394365	157.53**
Work pace (P)	2	3.52370783	62.44**
N x P	2	0.90028277	21.77**
Time at work (T)	3	0.00515195	0.84
N x T	3	0.01833381	5.11*
P x T	6	0.00893962	2.90*
N x P x T	6	0.00540362	1.24
Subjects (S)	5	0.54343712	
S x N	5	0.02529023	
S x P	10	0.05643120	
S x N x P	10	0.04135880	
S x T	15	0.00614475	
S x N x T	15	0.00358991	
S x P x T	30	0.00308225	
S x N x P x T	30	0.00435941	
Total	143		

* $p < .025$

** $p < .001$

were the noise condition x time at work, and the work pace x time at work interactions (Figures 7 and 8). Time at work within one-hour sessions was not significant as a main effect, i.e., there were no differences in overall performance among the four 15-minute time blocks.

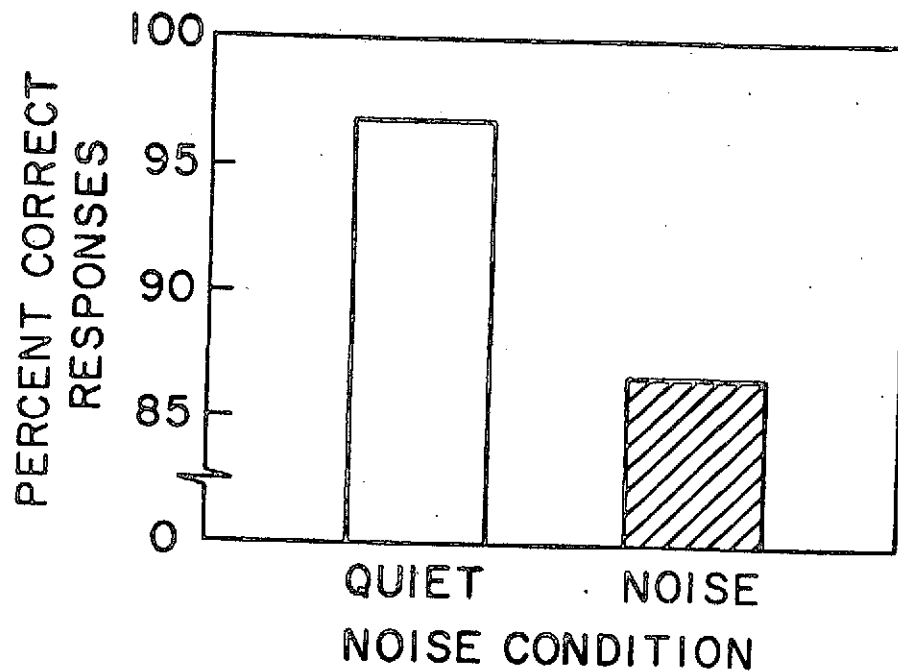


Figure 4. Effect of noise on task performance

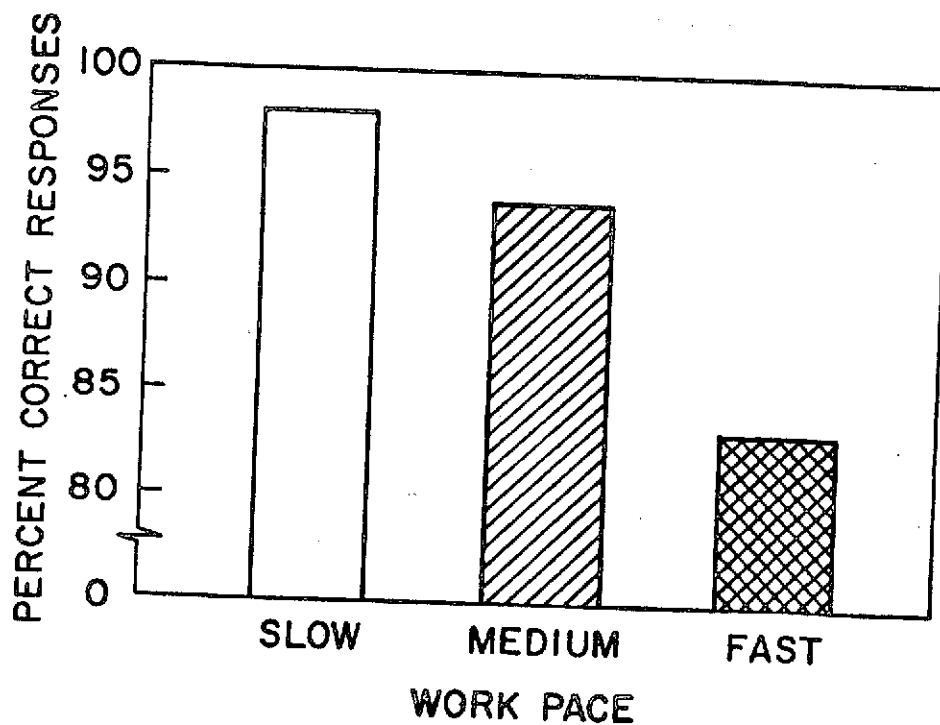


Figure 5. Effects of work pace on task performance

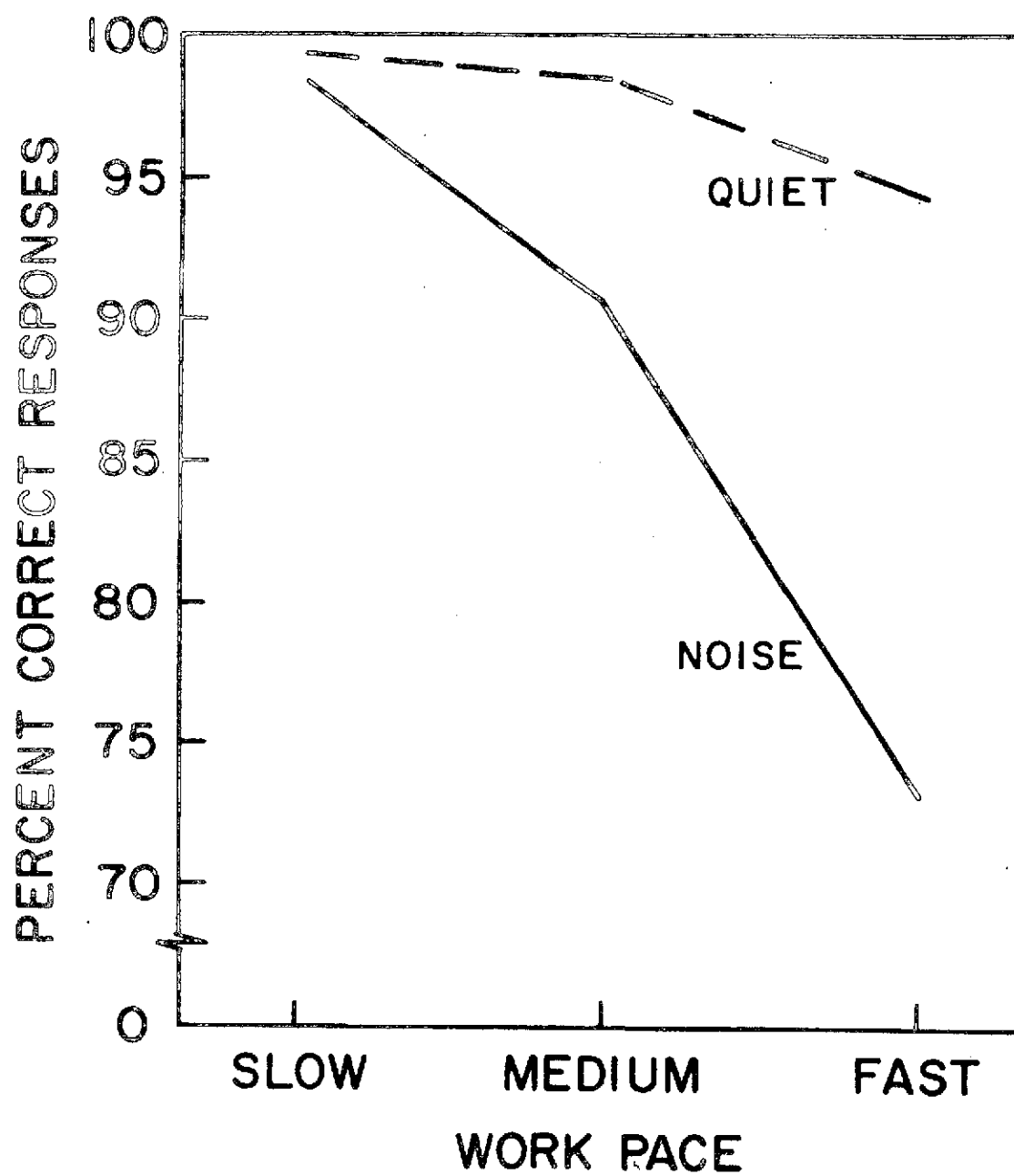


Figure 6. Interaction effects of noise and work pace on task performance

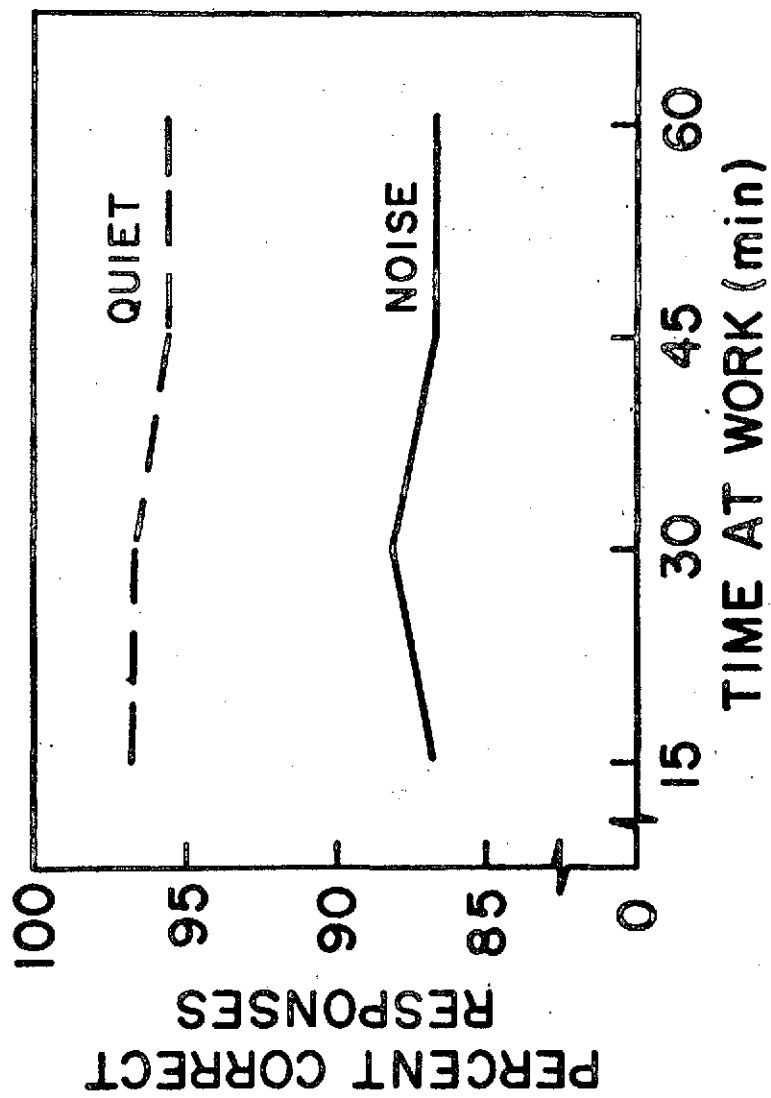


Figure 7. Interaction effects of noise and time at work on task performance

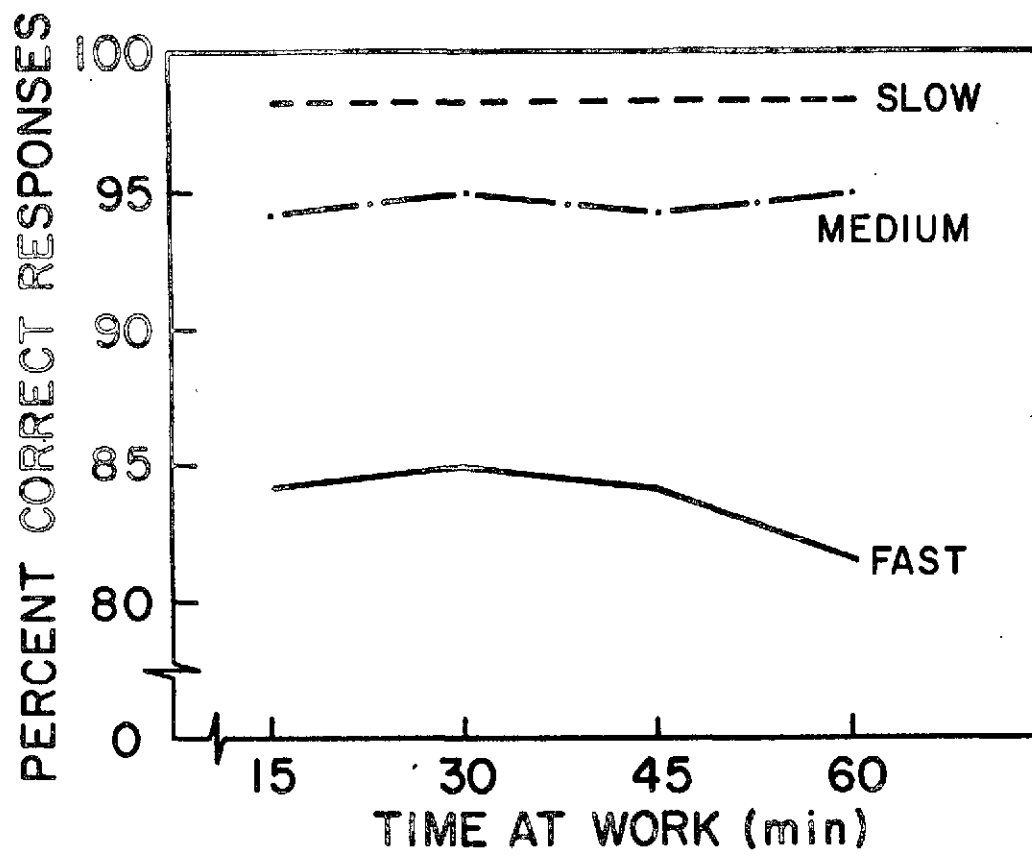


Figure 8. Interaction effects of work pace and time at work on task performance

Multiple comparisons between means for significant main effects, using Scheffe's procedure, showed that mean performance at the three work paces (slow, medium, and fast) were all significantly different from one another. The null hypothesis that mean performance at the fast work pace does not differ significantly from the average mean performance at the slow and medium work paces was rejected since the Scheffe statistic for this orthogonal contrast, 0.872, is clearly greater than 0.064, the critical value. Also, mean performance at the medium work pace was found to be significantly different from mean performance at the slow work pace, since the Scheffe statistic for this comparison, 0.200, is also greater than the criterion value of 0.064.

Using a procedure for interactions recently recommended by Harter (1970), multiple comparisons between differences in pairs of means for the noise condition x work pace interaction revealed that the difference between performance in noise and in quiet at the fast work pace was significantly different from that at both the medium and slow work paces, but that the difference between performance in noise and in quiet at the medium work pace was not significantly different from that at the slow work pace (see Figure 6). The latter did, however, approach statistical significance. The critical values ($p < .01$) for tests of ordered means two and three steps apart, with 10 df for the standard error of the mean, are 0.265 and 0.311 respectively. These values are exceeded by both the fast and medium work pace interaction elements and the fast and slow work pace interaction elements (0.366 and 0.535, respectively), but not quite by the medium and slow work pace interaction elements (0.169).

In summary, the statistical analyses (all of which are not reported here; cf. Cohen, 1972) revealed that overall performance in noise was significantly poorer than overall performance in quiet (Figure 4). Also, performance at the fast work pace was significantly poorer than performance at both the medium and

slow work paces, and performance at the medium work pace was significantly poorer than performance at the slow work pace (Figure 5). Further, noise affected performance more at faster work paces than at slower ones (Figure 6), as hypothesized. Stated another way, the faster the work pace, the greater were the adverse effects of noise on task performance.

This latter finding is supported by subjects' subjective reports. At the conclusion of the study on the last day, subjects were asked to comment on their performance under the various experimental conditions. All subjects reported that the fast work pace was the most demanding. Further, they all believed that the loud aperiodic noise adversely affected their performance, particularly at the fast work pace. (At no time during the actual study did subjects receive verbal feedback on their performance.) For example, several subjects stated that the loud noise made it difficult for them to attend to or concentrate on the task for very long. Other subjects stated that the fast work pace itself was stressful, but the loud aperiodic noise added to their feelings of stress. All believed that they made more errors in noise and at the fast work pace particularly.

In addition, subjects reported a number of physiological reactions indicative of a high state of autonomic arousal or stress, e.g., profuse sweating (particularly in the palmar and armpit regions), muscle tension (back of the neck and shoulders), hand and finger cramps, blanching of the hand and fingers, and feelings of finger coolness or numbness. It is well known and documented that people experience considerable individual differences in their autonomic response patterns to stress. It is not surprising, therefore, that subjects experienced several different reactions; however, all experienced at least one, and typically more, of the above reactions particularly while performing in noise at the fast work pace.

The adverse effects of noise are also reflected in the percent omissions data. Although these data were too few for statistical analysis, their trends support the data already presented, i.e., performance in noise was poorer than performance in quiet, particularly at the fast work pace. Omissions accounted for well under 1 percent of the total performance scores in quiet at both the slow and the medium work paces. However, percent omissions rose to about 1 percent of the overall performance scores in noise at the medium work pace and to just over 2 percent in noise at the fast work pace. Even though omissions were virtually extinguished during training, there was a definite tendency for them to increase in noise as a function of increased work pace, in added support of the noise condition x work pace interaction previously discussed.

Although the principal analysis of variance (Table V) failed to reveal a significant $N \times P \times T$ interaction, trend analyses of the six combinations of noise with work pace considered with regard to time on task indicated significant differences attributable to the fast work pace condition (Figure 9). While performance at the fast work pace in quiet decreased in linear fashion with time at work, under noise the plot of performance is characterized by an inverted-U shaped relationship (lower portion of Figure 9). Although some recovery of performance under noise occurs during the middle half hour, levels remain well below those attained in quiet. Presumably in this situation the deleterious effects of speed stress and time on task overcome subject effort to adapt to the noise stress.

Discussion

The results presented above confirmed the experimental hypotheses. In all cases performance in noise was consistently poorer than performance in quiet; the effects were reliable and consistent. Furthermore, the effects were not

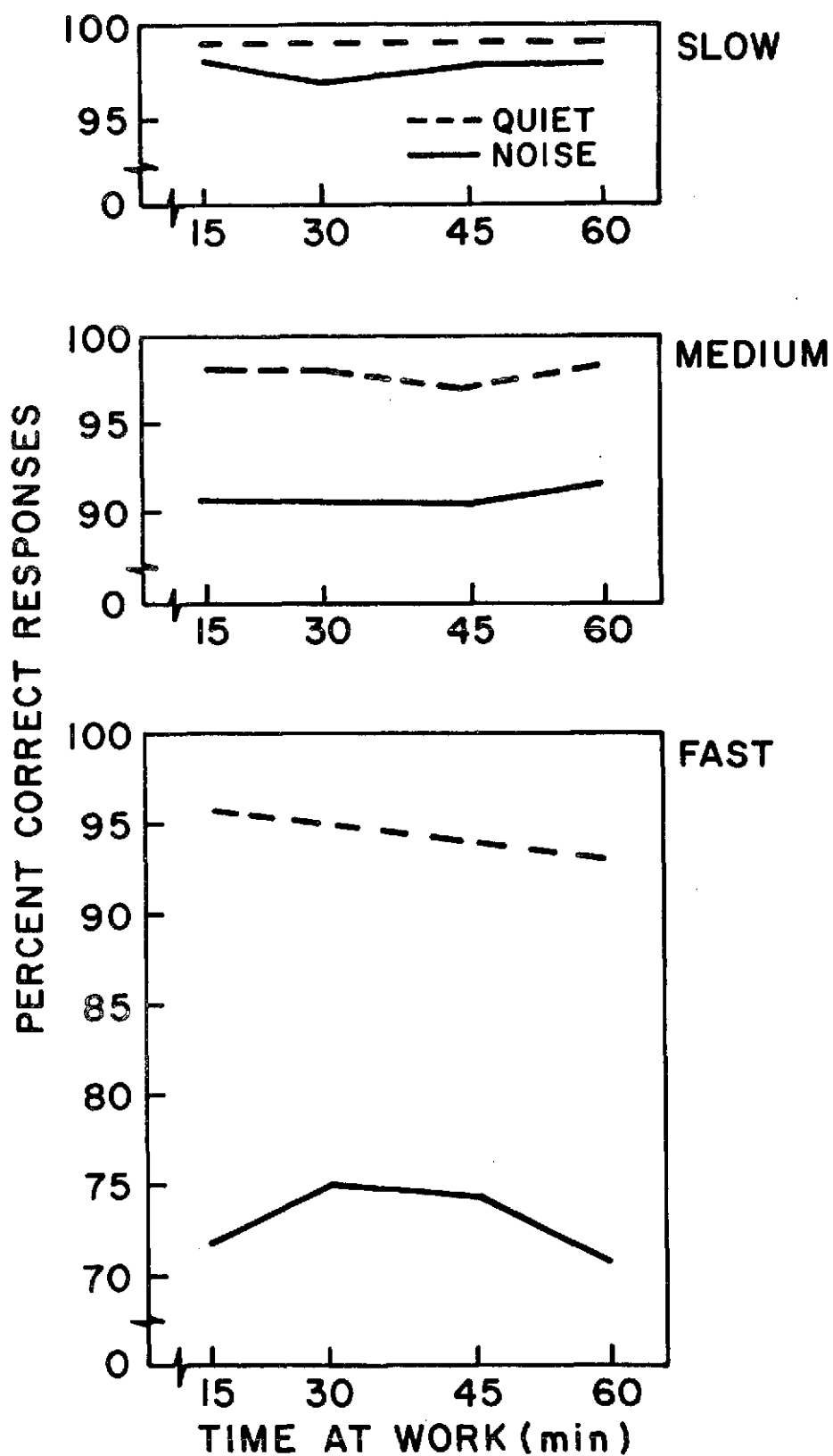


Figure 9. Interaction effects of noise, work pace, and time at work on task performance

transient, as has been suggested by Kryter (1970). Rather, performance in noise never adapted to levels as high as in quiet. Clearly, the results suggest the difficulty of adapting to loud unpredictable noise even if people are motivated to perform well and are well trained at their tasks, as well as the possibility that noise may facilitate the onset of work decrement due to time on task (work fatigue) when people must work at very fast work paces for prolonged periods of time.

Another issue raised by Kryter (1970) is resolved in the present study. Kryter suggests that it is difficult to ascertain from previous studies whether noise really affects performance or whether it affects only learning, since studies demonstrating adverse effects typically compare the performance of two separate groups of subjects, one performing in noise (experimental group) and one in quiet (control group). Further, subjects commonly are not well trained at their tasks, nor are they matched for performance skill. Through use of a Treatment X Subjects design, and by training subjects to asymptotic performance prior to introduction of experimental treatments, the present study answers these objections. The present findings therefore clearly demonstrate that noise adversely affects task performance, and not just skill acquisition.

The results of the present work further confirm the contentions of Broadbent (1957) and Hockey (1969) that reliable, consistent, and nontransient adverse effects of noise can be demonstrated if certain conditions of the task are met; i.e., the task should be long and continuous (over half an hour), it should require continual (or time-shared) attention, and it should present task information at a high rate. Similarly, the noise should be greater than 90 dB, variable in quality, or unpredictable in time.

As in the previously-described study in this report, the findings can be interpreted in terms of an arousal model. That is, noise increases arousal, and

in the case of a fast-paced task a condition of overarousal leading to performance degradation occurs as noise level is increased. The effect is on performance accuracy, i.e., correct responses, rather than upon speed of response. No evidence of lapses, or sporadic periods of inaccuracy, were apparent in the data.

Going beyond theoretical considerations several practical implications concerning human efficiency in suboptimal working conditions appear evident. A well-controlled field study by Broadbent and Little (1960) shows that a reduction of 8 to 10 dB, i.e., from about 99 dB to 89 dB, in a film production plant significantly reduced worker errors, e.g., number of broken rolls of film, but this did not affect speed of work, thus confirming laboratory findings. There was no sign that the effects found with these experienced workers (experienced at both their work tasks and with the noise environment) were less than those met on the much shorter time scale of the laboratory. The study demonstrates that noise does produce human error in a real-life situation, even amongst people who are supposedly used to it.

Finally, the study poses some implications for the health and well-being of a worker exposed to noise and speed stress. The subjective reports and physiological reactions indicate an undesirable stress state which if maintained on a day-in, day-out basis could have undesirable, cumulative effects on a worker's health. Such physiological costs of work should desirably be designed out of the worker's man-machine-environment system.

IV. STUDY 3: NOISE SENSITIVITY AND PHYSIOLOGICAL RESPONSE DIFFERENCES⁴

Statement of the Problem

The study to be described next was characterized by slight variations in the task and noise conditions found in Study 2. Thus the serial decoding task used

⁴Conducted by Donald W. Conrad

in Study 2 was programmed to require short-term memory storage of the displayed signals. It was reasoned that given a sufficiently complex task that would place considerable demands upon available operator channel capacity, significant impairment due to noise might be observed for a task requiring such cognitive activity. Since the task was externally paced, signal rate could be increased as high as practicable to ensure considerable mental loading. This type of task configuration was also considered to be highly analogous to practical situations in which a person (a) has to continuously decode information such as numerical dials or digital displays, and also (b) has to rely upon short-term memory while being engaged in rapid compensatory or control manipulations.

Most previous studies involving mental activity have used either continuous noise or short bursts of noise as the auditory stimulus (Jerison, 1954; Broadbent, 1958; Woodhead, 1964). Since it has been found, as noted previously, that perceptual-motor task performance is impaired under intermittent noise, it appeared that differential effects of different patterns of noise might also be observed for tasks characterized by cognitive activity. In the present study it is expected that noise effects will be greater for intermittent as compared with continuous noise due to the greater resistance of an interrupted stimulus to adaptation effects over time.

As may be obvious from the foregoing, our conceptual approach is again based upon arousal theory. In contrast to the two previous studies, physiological response measures were included in the present study in order to assess arousal effects. Together with arousal considerations, however, there is also the underlying concern for physiological costs of stress exposure. For example, Davies (1968) has concluded from the literature that there is evidence that exposure to 100 dB broadband noise while subjects are engaged in the performance

of a cognitive task adds significantly to the cost of mental work as indicated by measures of skin conductance, pulse interval, and muscle tension.

A third aspect of this study concerns existing evidence that the performance of somatic or anxious types of people tends to be affected by intense noise while more stable subjects are not so affected. Using the Heron personality inventory, Broadbent (1958) found that extroverts showed greater deterioration in a prolonged mental subtraction task than introverts; furthermore, extroverts showed more deleterious effects from 100 dB broadband machinery noise. Kryter's review (1970, pp. 547-550) cites additional evidence from other studies which reveal in general that subjects who are found to be "anxious," "introverted," or "somatic responsive" on the basis of personality ratings are more adversely affected by noise in the performance of mental (I. Q. tests and arithmetic) and motor tasks (reaction time and tracking) than are better adjusted subjects.

In order to assess further the factor of individual differences in task performance under noise exposure conditions, a paper and pencil test for assessing individual sensitivity to the annoyance properties of noise (Bregman and Pearson, 1972) was used in the present study. The factor of individual differences and subjective annoyance response has practical importance. For example, screening people on the basis of noise annoyance sensitivity has applications in personnel selection in industry, government, and transportation jobs where some environments may be characterized by continuous or intermittent intense acoustic noise.

In summary, the predictions of the present study were that significantly increased errors in performance at a basically mental task requiring considerable channel capacity would be exhibited under conditions of working at the task in noise at 93 dB(A) intensity as compared with working at the task in quiet. Furthermore, such decrements should be significantly differentiated with respect to the

type of noise pattern to which the subject is exposed. Differential decremental effects of noise on performance should also be accompanied by differential physiological activation effects, simultaneously, for different patterns of noise. Finally, high noise annoyance sensitive subjects should show greater performance decrements and higher physiological activation levels than low noise annoyance sensitive subjects under exposure to noise.

Method

Subjects. Sixteen undergraduate university students (14 male, 2 female) drawn from a general psychology course served as subjects. Each subject was screened for hearing loss and visual acuity deficits; all were right handed. In recruiting the subjects no reference was made to the topic of noise sensitivity.

Task Apparatus. The apparatus used in Study 2 and depicted in Figure 3 was used with certain modifications in task programming. The principal difference involved a requirement for short-term memory.

When a four-digit code and its accompanying green light were presented, the subject also had to memorize it in addition to making a response. Several more trials were then presented in which only the stimulus light came on. Responses to these trials were made from memory of the four-digit code from the first trial. After several trials were presented without the code being displayed, a new code appeared, and the cycle was repeated. The number of trials for which no code was presented varied randomly from two to five, inclusive, following each code presentation. Additionally, the order of presentation of the four green indicator (stimulus) lights and of the codes was randomized. Trial presentations were programmed in sets of 48 which included a code presentation on only 11 of the trials in a randomized sequence. Thus, remembering the code was required on all of the remaining 37 trials for a correct response

to be made by the subject. The subject had two seconds in which to make a response. The task was externally paced with a trial interval of two seconds and an intertrial interval of one second.

For purposes of the experiment the task display panel was located within a double-walled sound-proof chamber.

Auditory Stimulus Apparatus. Three types of audio stimuli were used: continuous broadband noise, intermittent regular or periodic noise, and intermittent irregular or aperiodic noise. The source for the audio stimuli consisted of 20 to 20,000 Hz--linear response--random noise generated by a Bruel and Kjaer type 1402 random noise generator. The audio stimulus was presented to the subject by means of a Telex type 1200-42 headset which also contained a microphone for 2-way communications during the experiment. By coupling the noise generator output to a logic network an intermittent regular or periodic noise stimulus was obtained. The network was adjusted for a 2.0-second on-period and a 2.0-second off-period. The third stimulus which consisted of an irregular intermittent or aperiodic noise was produced by coupling the continuous output of the random noise generator through an electromechanical timing circuit. The noise stimulus produced was characterized by on-periods of two seconds and off-periods that averaged 1.8 seconds. The following restricted randomization order corresponds to the presentation of the stimulus off-periods in seconds: 1.0, 3.0, 0.5, 1.0, 2.5, 2.0, 3.5, and 0.5. Considerable effort was made to ensure that the average length of the off-periods was as close as possible to the average length of the on-periods for the intermittent aperiodic stimulus as well as the intermittent periodic stimulus. Details of the logic network and timing circuitry appear in Conrad, 1972.

The continuous and intermittent outputs of random noise were adjusted to a level of 93 dB(A), at the headphones, by means of a Bruel and Kjaer type 4153 artificial ear in connection with a Bruel and Kjaer type 2603 microphone amplifier. The average sound level obtaining in the ambient or no-stimulus condition was found to be 38.8 dB(A).

Physiological Recording Equipment. Three physiological measures were recorded simultaneously with performance data recording. An electromyogram was obtained from the flexor carpi radialis and flexor digitorum sublimus muscle groups of the left forearm. In addition, photoplethysmographic blood volume pulse amplitude and rate were obtained from the middle finger of the left hand. Continuous records throughout each experimental session were obtained using a Grass Instruments Model 7 polygraph. The electromyogram recording electrodes were coupled to a 7P3 Grass Instruments physiological recording preamplifier which was adjusted to function as a continuous voltage-time integrator. The integrator circuit of the 7P3 preamplifier, in conjunction with the Model 7 chart drive assembly and driver amplifier, was used to display a unidirectional pen deflection which was proportional to the average level of the ongoing electromyogram signal. The amplitude of the tracing was a function of the amount of ongoing bioelectric activity at any given time.

Digital photoplethysmographic blood volume pulse amplitude was obtained from a transducer unit (Figure 10) designed by Conrad, 1972. A small rectangular aluminum box containing a Clairex CL704L photoconductive cell and two 4.5 v flashlight bulbs was constructed from 2 mm thick aluminum sheets and was secured by miniature nuts and bolts. The enclosure measured 6.9 cm long x 1.7 cm wide x 1.7 cm high and contained two holes that were 4 mm in diameter straddling a single 9 mm hole located in the center. The two 4 mm holes served as ports for

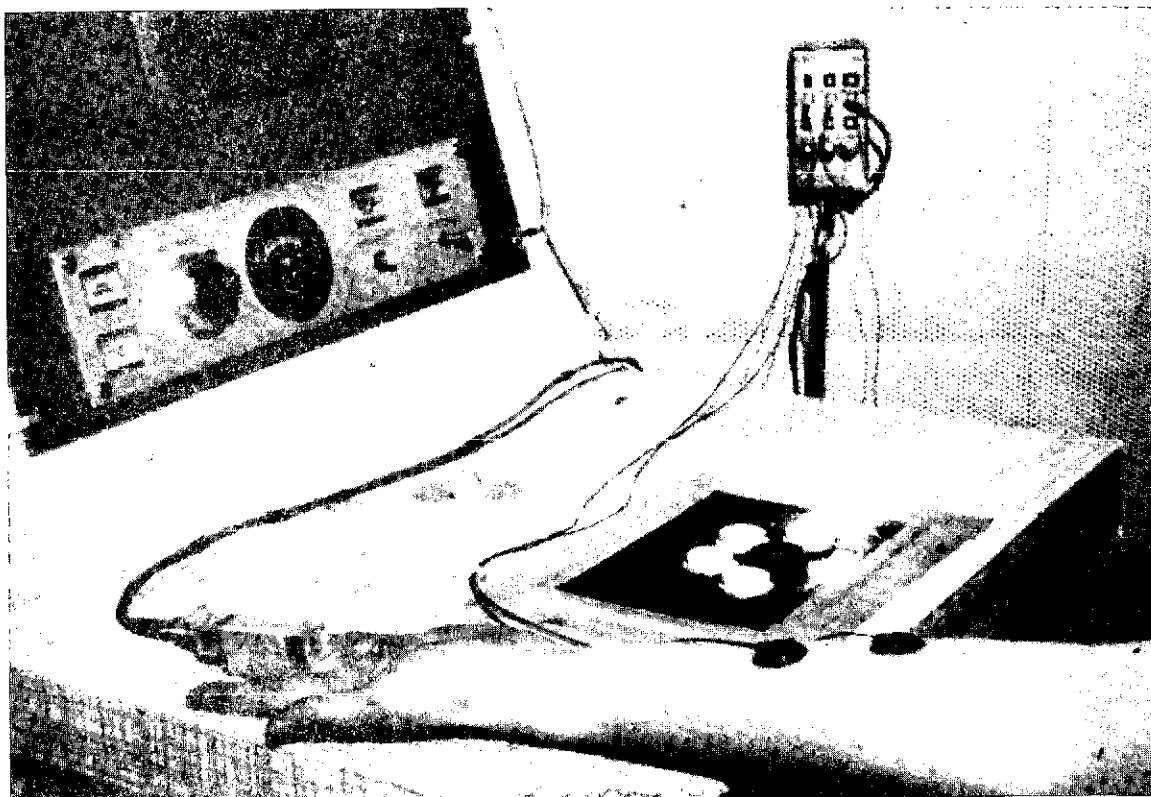


Figure 10. Photoplethysmographic transducer unit attached to finger.
(subject's hand is shown palm facing upward for clarity;
during actual recording trials, the hand and arm were
inverted from the position shown)

the two light bulbs, while the center hole functioned as a window for the photoconductive cell. The center hole was also covered with a 1 cm square piece of Wratten No. 89B gelatin filter material which served as an infrared filter screening most visible light rays from the photoconductive cell. The surface containing the ports was covered with a celluloid sheet and the remainder of the unit was taped for protection. The transducer was operated in conjunction with a control unit also constructed by the experimenter. The circuit used was one described by Brown (1967, p. 67) in which a full bridge arrangement was used for obtaining the recording output from the photoconductive cell.

The digital photoplethysmograph transducer described overcomes two principal disadvantages of commercially available units. First, some commercial units tend to be bulky and heavy. In contrast, the present unit is small enough to be held in place with a strip of masking tape and weighs only a few ounces. Secondly, the heat from the higher voltage bulbs in some units irritates subjects and can produce recording artifacts. The low voltage bulbs used in the present circuit, however, have negligible heat output.

For recording of the blood volume pulse amplitude, the output of the photoconductive cell bridge circuit was fed directly to a Grass Instruments 7P3 preamplifier functioning as a wide-band AC preamplifier. The resultant continuous primary recording of the basic blood volume pulse waveform was obtained by means of the Model 7 polygraph chart drive assembly.

Grounding of the instrumentation, room, and subject is described in detail in Conrad, 1972.

Test Materials. All subjects were ranked from highest to lowest according to their scores on a noise annoyance sensitivity questionnaire. The ranked subjects were then divided at the median into two blocks; the upper block was identified as high noise annoyance sensitive and the lower block was labelled low noise annoyance sensitive.

The questionnaire was composed of a subset of 74 items originally used in the development of a predictive model for noise annoyance sensitivity in adult subjects (Bregman and Pearson, 1972). Prior to conduct of the present study the Bregman-Pearson scale was administered to a sample of 35 introductory psychology students who later rated the annoyance value of six sounds presented in the simulated living room environment. A subset of 15 highest predictor items was chosen, using statistical multiple regression techniques, in addition to appropriate item regression weights. Then, in the present study, each subject was given a test booklet containing items numbered 10 through 74 of the original 74 test items, but only the 15 highest predictor items chosen for psychology students were used in calculating an individual's test score.

Procedure. Following audiometric screening each test subject was taken into the chamber and indoctrinated by the experimenter on task procedures. The subject was then given an initial 25 to 30 practice trials with feedback concerning progress. The experimenter then monitored a longer practice session of about five minutes with the chamber door closed. Performance

accuracy was checked at regular intervals--every 25 trials--until a criterion level of at least 50 percent correct responses was attained; this was followed by a performance stabilization period of 150 trials.

Following the training period, instructions for responding to the noise annoyance sensitivity questionnaire were given by the experimenter while the subject read along simultaneously. Upon completion of the questionnaire (which required approximately 15 minutes) the test materials were collected and instructions for the four experimental sessions were read aloud by the experimenter. A briefing on physiological recording procedures was also read. The subject was then allowed to relax outside the chamber until preparations for physiological recording were completed. Next, the subject was reseated in the chamber and, as depicted in Figure 10, two recording electrodes were attached to the left forearm in a standardized lead configuration (Venables and Martin, 1967, Ch. 8) for continuous passive recording of muscle activity from the flexor carpi radialis and flexor digitorum sublimus muscle groups. Passive recording was chosen in order to minimize task involvement of the muscle groups under consideration. The photoplethysmographic transducer was then attached (Figure 10) to the dorsal surface of the middle finger phalanx of the left hand (Brown, 1967, Ch. 2; Venables and Martin, 1967, Ch. 6) using a 5-inch strip of 1-inch masking tape. The left arm holding the entire preparation was then positioned comfortably immediately to the left of the response keys; a strip of masking tape was lightly applied over the wrist and onto the task keyboard panel as a reference point for

the subject. A grounded earclip necessary for the electromyogram was then attached to the subject's right ear lobe. The headphone set was positioned as comfortably as possible and over the ear lobe clip. Intercommunications were then tested and the chamber door closed. During the ensuing 10-minute rest period, physiological baselines were established and sensitivity calibrations were performed.

The investigator then announced the start of session number one. The experimental conditions were presented in a restricted randomization counter-balanced order according to the following schedule:

<u>Subject</u>	<u>Sequence</u>	<u>Key</u>
S1	Q C P A	Q work in quiet
S2	A P C Q	C work in continuous noise
S3	C Q A P	P work in periodic noise
S4	P A Q C	A work in aperiodic noise
.	
.	
SN	Repeat	

At the conclusion of session number one, the experimenter announced that the subject should rest but cautioned against disturbance of the recording preparations. Each of the four experimental conditions was conducted in the same manner and consisted of 105 to 115 trials for a duration of five minutes each. During three intervening subject rest breaks of ten minutes each, the experimenter had time to rebalance the bridge circuit of the photoplethysmograph, to recheck recording baseline positions, and to prepare the next sequence of experimental conditions. The rest periods also served the important function of allowing time for physiological response recovery, and for rebounding from

previous stimuli to subside, prior to restimulation in order to avoid confounding of responses with each other (Sternbach, 1966, p. 78).

Digital counters registered the total number of trials presented, the total number of trials attempted, and the total number of correct responses.

Results⁵

Performance Data. The number of errors committed within each experimental condition lasting for five minutes each was first converted to a percentage score by dividing by the total number of trials presented during the given experimental condition. A similar error score was also calculated for each subject's 150-trial training baseline. A given subject's baseline error score was then subtracted from each of his experimental condition error scores. This procedure was followed in order to subtract out the factor of individual ability differences. The resultant difference scores were then entered as the data points in a two-factor analysis of variance with repeated measures on one factor (Winer, 1962, p. 302). The same statistical procedure was also utilized for the statistical analysis of blood volume pulse amplitude, pulse rate, and electro-myogram.

Based on a test for non-normality of the mean error data (discussed in Conrad, 1972) it was decided that an arc sin transformation should be performed prior to statistical analysis. Results of the analysis of variance appear in

⁵Due to difficulties encountered in physiological data recording not all subjects could be included in the separate analyses. A subset of 10 subjects was used in the digital vasoconstriction response analysis, and 12 subjects were included in the pulse rate and forearm muscle activity analyses. Despite this variation in sample size for the respective dependent variables, no other data observations had to be omitted; all samples were of equal size within any given dependent variable's factorial analysis. In addition, all subjects were treated under identical experimental conditions.

Table VI, while Table VII lists the means for levels of the two principal independent variables of interest and for their interaction (cells). The noise condition factor was not statistically significant (Table VI),

TABLE VI. ANALYSIS OF VARIANCE (ERROR SCORES)

Source	df	SS	MS	F (df)
Noise Annoyance Sensitivity	1	234.13	234.13	1.53 (1, 14)
Subjects Within Noise Annoyance Sensitivity	14	2144.83	153.20	-
Noise Condition	3	24.17	8.06	0.35 (3, 42)
Noise Annoyance Sensitivity x Noise Condition	3	113.77	37.92	1.64 (3, 42)
Subjects x Noise Condition Within Noise Annoyance Sensitivity	42	969.26	23.08	-

the mean error scores (Table VII) under continuous, periodic, and aperiodic noise being only slightly different from that in quiet.

Although the mean error score for high sensitive subjects was higher than that for low sensitive subjects (Table VII), the analysis of variance (Table VI) indicates that this effect falls short of being statistically significant. Finally, from Table VI, no significant interaction effects are to be noted.

TABLE VII. MEAN ERROR SCORES AS A FUNCTION OF NOISE CONDITION AND SUBJECTIVE NOISE ANNOYANCE SENSITIVITY

Noise Annoyance Sensitivity	MEAN ERROR SCORES				
	Noise Condition				Mean
	Quiet	Continuous	Periodic	Aperiodic	
High	-7.44	-8.88	-4.97	-7.62	-7.23
Low	-14.09	-13.19	-14.98	-12.93	-13.80
Mean	-10.77	-11.03	-9.98	-10.28	

Questionnaire Response Data. Kendall tau correlation coefficients and significance tests between the noise annoyance sensitivity scores and observed dependent variable responses appear in Table VIII. Significant correlations were

TABLE VIII. KENDALL TAU CORRELATION COEFFICIENTS FOR SUBJECTIVE NOISE ANNOYANCE SENSITIVITY AND DEPENDENT VARIABLES

<u>NOISE CONDITION</u>		
<u>CONTINUOUS</u>	<u>PERIODIC</u>	<u>APERIODIC</u>
<u>Error Scores</u>		
+0.05 (N. S.)	+0.25 (N. S.)	+0.18 (N. S.)
<u>Blood Volume Pulse</u>		
+0.56* (p < .02)	+0.47* (p < .04)	+0.51* (p < .03)
<u>EMG</u>		
-0.09 (N. S.)	+0.06 (N. S.)	-0.06 (N. S.)
<u>Pulse Rate</u>		
+0.49* (p < .04)	+0.27 (N. S.)	+0.30 (N. S.)

found under all three noise conditions for the blood volume pulse variable, and for pulse rate only under continuous noise.

Vasoconstriction Response. Blood volume pulse amplitude was measured in millimeters directly from the record. The measured vertical distance between a given systolic peak and the immediately preceding diastolic trough gave a relative indication of digital pulse pressure. Six of these waveforms were measured consecutively at intervals located 30 seconds apart throughout a given 5-minute exposure condition. All of the individual measurements were then averaged and the mean amplitude was afterwards multiplied by the calculated recording sensitivity level. The result was a mean voltage density function in millivolts that was directly proportional to pulse pressure (the measured distance between systolic peak and diastolic trough). Vasoconstriction, in turn, was inversely proportional to the pulse pressure or blood volume pulse amplitude (Brown, 1967). No data were analyzed during the first two minutes of any experimental condition in order to allow physiological response recovery and stabilization to occur. This procedure was used for all of the measured physiological variables. The mean blood volume pulse amplitude, in millivolts, obtained for a given subject's resting baseline was then subtracted from his mean blood volume pulse amplitude under each experimental condition. The resulting change scores or directional shifts from resting baseline then served as the data points for the statistical analysis.

As shown in Table IX, digital vasoconstriction response was higher under the three noise conditions than under the quiet condition. A separate analysis of variance here revealed this effect to be statistically significant beyond the .03 level (cf. Conrad, 1972). Increased vasoconstriction is represented by large negative shifts from the resting baseline. A Newman-Keuls test for repeated measures designs (Winer, 1962, p. 309) was performed on the treatment means. The results showed that the mean shifts were significantly different between continuous noise and quiet, periodic noise and quiet, and aperiodic noise and quiet. Results were significant beyond the .05 level of significance.

TABLE IX. VOLUME PULSE RESPONSE, PULSE RATE, AND FOREARM
ELECTROMYOGRAM AS A FUNCTION OF NOISE CONDITION
AND NOISE ANNOYANCE SENSITIVITY

PHYSIOLOGY DATA MEANS					
Volume Pulse Response--Millivolts					
Noise Annoyance Sensitivity	Noise Condition				Mean
	QUIET	CONTINUOUS	PERIODIC	APERIODIC	
HIGH	-16.22	-21.82	-23.52	-24.01	-21.39
LOW	1.67	-2.72	-0.98	-1.01	-0.76
Mean	-7.27	-12.27	-12.25	-12.51	

Pulse Rate--Beats Per Minute					
Noise Annoyance Sensitivity	Noise Condition				Mean
	QUIET	CONTINUOUS	PERIODIC	APERIODIC	
HIGH	7.03	8.01	4.67	7.89	6.90
LOW	6.49	2.62	4.36	6.10	4.89
Mean	6.76	5.31	4.51	6.99	

Forearm Electromyogram--Microvolts					
Noise Annoyance Sensitivity	Noise Condition				Mean
	QUIET	CONTINUOUS	PERIODIC	APERIODIC	
HIGH	-4.32	-1.11	-0.36	0.58	-1.30
LOW	-4.67	-4.21	-2.81	-3.84	-3.88
Mean	-4.49	-2.66	-1.58	-1.63	

Vasoconstriction response for high noise annoyance sensitive subjects (-21.39) was found to be higher than that of the low noise annoyance sensitive subjects (-0.76) as also shown in Table IX. This difference was statistically significant beyond the .01 level of significance as revealed by analysis of variance (Conrad, 1972); no significant interaction effect between noise sensitivity and noise condition was noted here, however.

Pulse Rate Data. Pulse rate was sampled at 30-second intervals to coincide with the sampling epochs for blood volume pulse and electromyogram. The rate was estimated at these points by counting the number of pulse waveforms in a 10-second period and multiplying the result by six. This procedure yielded estimated beats per minute at the chosen time period. The criterion for rejection of any given waveform which occurred only partially in a given sampling period was the omission of 50 percent or greater of the pulse wave from the sample. The mean pulse rate was then calculated for each experimental condition and for the resting baseline. The baseline mean rate was then subtracted from each experimental condition mean rate to obtain the change scores or directional shifts from resting baseline. These served as the data points for statistical treatment.

It was found that high noise annoyance sensitives had slightly higher mean rate shifts (6.90) than low noise annoyance sensitives (4.89) as shown in Table IX; in addition, some slight differences were shown across noise treatment conditions. However, none of these differences were statistically significant, nor were there any significant interaction effects (Analysis of variance summarized in Conrad, 1972).

Forearm Electromyogram. In order to calculate the average level of ongoing bioelectrical activity for one experimental period of five minutes, a sampling procedure was devised that would render a reasonably accurate estimate and also be as free as possible from subjective bias. Sampling points were chosen every 30 seconds on the record to coincide with the sampling points of blood volume pulse amplitude and pulse rate estimation with respect to time. Each sampling point chosen in this manner comprised a two-second epoch of the integrated trace within which the amplitude of the trace was measured at the peak of every prominent upward excursion and the trough of every prominent downward excursion of the trace. "Prominent" meant that the slope of the trace at a given peak or trough underwent a change in direction in excess of 90 degrees. Where the record appeared to be relatively flat and to contain few if any prominent peaks, the amplitude was measured at 0.5 second intervals. All measurements were made relative to a preestablished recording baseline pen deflection. The measurements, in millimeters, were then averaged under each experimental condition and converted to microvolts by multiplying the mean amplitude by the recording sensitivity level. Next, the calculated mean muscle activity level for the resting baseline condition was subtracted from each of the experimental condition mean activity levels. The resulting shift scores were then statistically analyzed.

In the results, Table IX, large negative shifts from resting baseline indicate less activation under stimulus conditions. While it is noted that average muscle activity was slightly higher in noise than in quiet, and also higher for high sensitive subjects than for low sensitive subjects, an analysis of variance (Conrad, 1972) indicates that none of these differences are statistically significant. There were also no significant interaction effects.

Discussion

The results of this study are in line with other studies that indicate little if any decremental effects of noise on performance for tasks that involve primarily mental activity or thinking such as arithmetic or problem solving. The results of the present study indicate that performance at a rapid serial decoding task involving a short-term memory component will not be significantly affected by continuous or periodic and aperiodic intermittent patterns of broadband noise presented at a level of 93 dB(A). This is the case, at least, for the task parameters chosen in this study.

Such continued good performance was, however, accompanied by a somewhat increased intensity of effort in the form of a significant increase in cutaneous vasoconstriction response. Furthermore, the increased cost of maintaining a high performance level was significantly higher for persons who were highly annoyed by noise than for persons who were less annoyed by noise. In addition, a significant relationship was found between noise annoyance sensitivity and blood volume pulse (BVP) response for continuous, periodic, and aperiodic noise conditions.

To the extent that the intensity with which work is performed is linked with physiological activation, increased activation can be said to reflect an increase in intensity of effort or cost of work. The extent of this interrelationship varies in different studies but appears to be clear enough to indicate a genuine connection. In a study by Ryan, Cottrell and Bitterman (1950) it was found that subjects who maintained their normal levels of performance under conditions of noise and glare showed a greater increase in muscle tension than subjects whose performance was impaired. Pinneo (1961) has shown that externally induced muscle tension resulted in widely generalized physiological activation as indicated by significant increases in palmar conductance, muscle potentials, respiration rate,

heart rate, and EEG activity. Simultaneously, performance at an auditory tracking task (involving right foot pedal conformance to a function generated signal) was significantly impaired. In his review of the effects of exposure to high intensity noise, Davies (1968) concluded that when subjects who are engaged in the performance of a cognitive task are simultaneously exposed to 100 dB of broadband noise there is sufficient evidence that the noise adds "slightly but significantly" to the cost of mental work as indicated by physiological measures of skin conductance, muscle tension, and pulse interval.

Beyond increased cost of work (as evidenced by significantly higher vasoconstriction under noise) the results of the present study might have a basis in an arousal hypothesis explanation of noise effects on performance if activation was actually at an optimal level. Reference to Tables VII and IX reveals that the sample means for high annoyance sensitive subjects are displaced in a direction intuitively predicted by an arousal hypothesis; i.e., high annoyance sensitives show greater EMG activation, greater BVP activation, higher pulse rate, and increased error scores. However, only BVP activation was statistically significant. The level used in this study (93 dB(A)) has, however, been identified in some studies as the approximate level below which noise effects on performance were not observed. It may be that for higher levels of intensity than those used in the present study all four dependent variables would be significantly increased. Such a result might be observed for intensity levels of between 95 and 110 dB(A).

In addition, the factor of task parameters is of critical importance. Freeman (1938) has suggested that the optimal degree of muscle tension that defines the transition point between improvement and impairment of performance becomes lower as task difficulty is increased. Ray (1965) has also shown that increased pressure for speed leads to progressively poorer performance in solving relatively difficult problems. It has also been argued that level of arousal

risers with strength of incentive and that the task itself induces a degree of arousal which increases with its difficulty. Moreover, the task-induced arousal is added to that arousal produced by the incentive (Welford, 1968, p. 271). The task in the present study used trial intervals of two seconds combined with a 1-second intertrial interval. An increase in speed stress (as in the case of Study 2) could also increase the probability of a significant increase in errors under noise--especially for a higher intensity level of noise. In any event, it has been demonstrated in the present study that a subjective measure of noise annoyance sensitivity might be used to predict subjects' autonomic responses under exposure to intense auditory stimulation.

A basic question in psychophysiology--the extent to which individuals differ in their physiological functioning--unites the traditional interest of the psychologist in individual differences with the interest of the physiologist in normal functioning. However, few physiological referents for psychological concepts are known in detail. Only sensation and, to a more limited extent, emotion and anxiety are known to have specific physiological referents. Hence, the issue of physiological differentiation of psychological concepts by peripherally available measures is not a settled issue. To the investigators' knowledge, the results of the present study showing a significant relationship between subjective noise annoyance sensitivity and a measured autonomic variable (digital photoplethysmographic response) have not been previously reported.

V. SUMMARY AND CONCLUSIONS

1. Three studies of noise effects upon human information processing have been described. The individual studies involved both different types of noise exposures and different task characteristics, and thus, perhaps not surprisingly, results (noise effects on performance) varied.

- a) In the first study 80 dB noise (speech played in reverse) was presented at the task only in connection with the onset of a visual signal requiring a response. As compared to quiet, auditory stimulation was found to speed up the processing of signals. This facilitation was attributed to increased arousal. The findings question Broadbent's position that arousal can be augmented only when the "neural filter" selects noise stimuli at which time response to task information is not possible. It would appear that noise is not completely rejected by the nervous system when man is processing information. Task difficulty (signal complexity) was also varied in the study, and contrary to expectations, fastest processing occurred for the most complex signal; additionally, there was no significant interaction between signal complexity and noise. Finally it was concluded that the facilitative effect of noise in this study occurs not at the level of attentional processes but at a more central level.
- b) Speed stress (work pace) was a variable in the second study. Auditory stimulation consisted of rapid, intermittent pulses of constant duration, broadband 100 dB(A) noise separated by rapid, variable internoise intervals. Continuous attention to the task for a period of one hour was required of subjects. It was found that noise adversely affected performance on the task; the faster the work pace, the poorer was performance; noise more adversely affected performance at fast work paces than at slower work paces; and performance in noise at fast work paces deteriorated disproportionately with time at work. In short, effects were not transient, performance under noise never adapting to levels attained

in quiet. The results emphasize the difficulty of adapting to loud, unpredictable noise even when people are motivated and trained for the task; further, noise can facilitate the onset of work decrement when the task involves a fast work pace and is continued over time without desirable rest periods. The performance effect of noise observed in this study involved correct responses, or accuracy, rather than speed of response; this should be noted by those who are concerned with the error-free, or safe, behavior of employees. Finally, subjective complaints of subjects in this study pose implications concerning the health and well-being of workers exposed to combinations of noise and speed stress.

- c) The third study used the same basic apparatus as the second, adding a short-term memory component and eliminating the speed stress emphasis. While a variety of noise stimuli were used (continuous, periodic, aperiodic--all at 93 dB(A)) no significant performance effects were obtained. However, performance under noise was accompanied by increased effort as reflected by cutaneous vasoconstriction; further this "cost" was higher for subjects classed as "high noise sensitive" in contrast to those classed as "low-sensitive." Finally, a significant relationship between noise annoyance sensitivity test scores and blood volume pulse responses under the three noise conditions was found.

2. The effects of noise on performance are difficult to predict. It is clear from these studies and similar ones that the occurrence of noise effects on human performance is dependent upon a number of factors, often involving their interaction; these factors include: (a) noise intensity;

(b) "type" of noise--both in terms of spectral and of "impulse" characteristics; (c) temporal characteristics of noise, e.g., continuous, periodic, or aperiodic; (d) time correlation (phasing) between noise stimulation and task signal presentations; (e) the nature of the task in terms of signal complexity (load stress) or speed stress; (f) the nature of human abilities involved in the task, e.g., attentional, cognitive; (g) the level of arousal and of motivation of the subject; and (h) the sensitivity of the subject to noise as reflected in his attitudes and personality structure.

3. The results of all three studies were interpretable in terms of arousal theory; this encourages use of this theoretical position in prediction of noise effects on task performance. For example, one might predict that potential modifiers of arousal other than those in these studies (e.g., drugs, other environmental stressors) would interact with noise and/or task stress to affect performance.
4. It is felt that the findings support the view that the concepts of speed stress and load stress involve useful dimensions which can be related to whether a task situation is susceptible, or not, to adverse performance effects from noise exposure.

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